

Intelligence and neural efficiency as determined by EEG-Coherence

Schrausser D.G., Fink A. & Neubauer A.C.

Institute of Psychology, University of Graz, Austria

<http://psyserver.kfunigraz.ac.at/diff/diffpsy.html>

Introduction

Beneath EEG mapping methods (e.g. Event Related Desynchronization, ERD) which focus on the level of cortical activation the coherence parameter is used to assess the level of functional coupling of brain areas. By means of the EEG coherence analysis anatomical connections (Fein, Raz & Merrin, 1988) as well as functional coupling (Thatcher, Krause & Hrybyk, 1986) of different brain areas can be described (Busk & Galbraith, 1975; Sklar, Hanley & Simmons, 1972). As there is strong empirical evidence that highly intelligent individuals display a more focused pattern in contrast to a more global pattern of activation during cognitive performance they should be characterized by a lower ERD as well as a lower task related coherence (i.e. Beaumont, Mayers & Rugg, 1978; Thatcher, McAlaster, Lester, Horst & Cantor, 1983; Gasser, Jennen-Steinmetz & Verleger, 1987 and Weiss, Rappelsberger & Petsche, 1995). Findings concerning gender related coherence differences caused by sexual dimorphism of the brain's structure and physiological properties even suggested the expectation of possible IQ by sex interactions (i.e. Gur et al., 1995; Haier, 1995; Mansour, Haier & Buchsbaum, 1996; Bishop & Wahlsten, 1997; Corsi-Cabrera, Arce, Ramos & Guevara, 1997; Rabinowicz, Dean, Mc Donald-Comber Petot & DeCourten-Myers, 1998; DeCourten-Myers, 1999; Lynn, 1999; Nopoulos, Flaum, O'Leary & Andreasen, 1999; Skandries, Reik & Kunze, 1999; Rescher & Rappelsberger, 1999; Lynn, Allik & Must, 2000 and Nyberg, Reza & Herlitz, 2000).

Method

Participants

From a pool of $N = 167$ persons which were recruited through local newspaper advertisements and which were tested with a variety of psychometric tests we selected $n = 60$ participants for the EEG study by means of their general mental ability scores. Because of EEG artifacts 8 persons had to be excluded, the remaining sample included 26 males and 26 females. Based on the general IQ-score the entire sample was divided into two groups: The group with lower IQs comprises participants with IQs from 82 to 103, the higher IQ group included participants from IQ 109 to 131.

Elementary Cognitive Tasks

Three modified versions of Posner's classical letter matching task (Posner & Mitchell, 1967) were used, employing verbal, numerical and figural-spatial stimulus material. The participants were simultaneously shown pairs of stimuli on a computer screen which were either of identical or of a different name. Originally, ECTs consisting of verbal (i.e. letters), numerical (i.e. arabic and "domino" numbers) and figural-spatial (i.e. arrows) stimuli were used (cf. Neubauer et al., 2000).

EEG Recording

The EEG was measured by means of gold electrodes in 27 positions, according to the international 10-20 system. The EEG was monopolarly recorded against nose. Electrode impedances were kept below 5 k Ω . All signals were amplified with low and high cut filters set at 0.3 s and 75 Hz. EEG data were digitized at a sampling rate of 128 Hz.

Selection of individually adjusted frequency bands

Frequency windows for the analyzed bands were determined individually for each participant by using the highest amplitude (peak) in the alpha band as an individual anchor point to identify the dominant EEG frequency (see Klimesch, 1999).

Coherence

After the Laplacian procedure coherences were calculated between 7 interhemispheric and 14 intrahemispheric electrode pairs (7 left sided and 7 right sided) in 21 positions. For the interhemispheric coherence long distance pairs were calculated between F₇-F₈, T₃-T₄ and T₅-T₆, short distance pairs were calculated between F₃-F₄, C₃-C₄, P₃-P₄ and O₁-O₂. Intrahemispheric pairs were defined as F₄-C₄, F₈-T₄, C₄-P₄, T₄-T₆ and P₄-O₂ for short distance right hemispheric, F₃-C₃, F₇-T₃, C₃-P₃, T₃-T₅ and P₃-O₁ for short distance left sided, F₄-O₂ and F₈-T₆ for long distance right sided and finally F₃-O₁ and F₇-T₅ for long distance left hemispheric. As period for the task related coherence analysis (ERCoh) served a 125 ms time interval starting 250 to 125 ms before participant's response, the so-called pre-reaction interval (PRI). Fisher's Z-transformation was applied in order to enforce normality.

Procedure

After the mounting procedure EEG was recorded in a 5 minute resting state with eyes closed. The matching tests were presented in two blocks. The first block consisting of 16 items allowed the participant to practice the task. During the second block of 80 items EEG was recorded. The order of trials within the letter matching tests was pseudo-randomized. After the matching tests a second 5 minute EEG at rest with eyes open was recorded. Between the presentations of the three matching tasks (i.e. verbal, numerical and figural-spatial variant) short breaks of 3 minutes were allowed. Each experimental test condition took about 20 to 25 minutes per participant resulting in a total time of about 1 to 1¼ hours.

Results

To determine possible Intelligence group (IQ) by gender (sex) by content differences with respect to ERCoh in the PRI interval of the matching test the averaged Z-transformed coherence scores (Z_{coh}) for long and short distance interhemispheric (InterL and InterS, respectively) as well as for long and short distance intrahemispheric pairs (right IntraLr, IntraSr and left IntraLi IntraSl) for the individual theta, lower-1 alpha, lower-2 alpha and upper alpha band were analyzed by means of three-way analyses of variance (ANOVAs) with task content (figural, numerical, verbal) as within subjects variable and IQ and sex as between subjects variables. First, all the interhemispheric coherence scores for all frequency bands with the only exception to the short distance coherency in the upper alpha band did produce a significant IQ by sex interaction. In all cases long as well as short distance coherence differences were found in similar patterns which were that low IQ females display a higher coherence score than high IQ females

while for males this is of reversed order and far less pronounced. Post hoc comparisons by means of Newman-Keuls tests revealed significant coherence differences only for women, while *Zcoh* differences for men failed to reach significance.

For the theta band's InterL coherence score, ($F [1, 48] = 10.55, p < .01$) males show a much lower IQ groups difference (IQ low 0.14 vs. IQ high 0.25, *n.s.*) than females, with this difference going in the opposite direction (IQ low = 0.34 vs. IQ high = 0.17, $p < .05$), brighter women display a much lower ERCoh score compared to low IQ women, which show the highest score ($Zcoh = 0.34$) for the long distance interhemispheric theta band coherences. The same pattern can be observed for the InterS coherence scores in the theta band ($F [1, 48] = 10.12, p < .01$). Again, men show lower coherence differences in the IQ groups (IQ low = 0.40 vs. IQ high = 0.54, *n.s.*) compared to women's reversed order findings (IQ low = 0.62 vs. IQ high = 0.43, $p < .05$).

Similar results as for the theta band described above emerged for the two Lower alpha bands. Both, the lower-1 alpha's InterL ERCoh ($F [1, 48] = 7.43, p < .01$) and InterS ERCoh ($F [1, 48] = 6.14, p < .05$) as well as lower-2 alpha's InterL ERCoh ($F [1, 48] = 5.94, p < .05$) and lower-2 alpha's InterS ERCoh scores ($F [1, 48] = 4.48, p < .05$) appeared consistently in the same pattern of interaction.

Further consistent findings resulted for *intrahemispheric* task related coherence: Interestingly, only long distance coherence scores were found to be significant: To report theta and lower-1 alpha band results, here both, right ($F [1, 48] = 10.31, p < .01$; $F [1, 48] = 5.04, p < .05$, respectively) and left ($F [1, 48] = 9.56, p < .01$; $F [1, 48] = 6.59, p < .05$, respectively) intrahemispheric long distance coherences reached significance.

In all cases we found the same patterns of interaction as reported above. Alike the interhemispheric task related coherence score for the long distance intrahemispheric score low IQ women are characterized by a much higher coherence compared to brighter women. In contrast to women's results as shown by means of Newman-Keuls' post hoc comparisons men are again characterized by non significant differences between IQ groups' ERCoh score.

Discussion

A consistent pattern of significant IQ by sex interaction was found for low frequency band's long and short distance interhemispheric and long distance intrahemispheric task related coherence score. While males show no significant ERCoh differences between IQ groups, females display significant lower ERCoh scores in the high IQ group compared to females' low IQ group. This interaction is especially pronounced for the theta and lower-1 alpha bands. This finding is in accordance with our expectations concerning coherence difference between intelligence groups. Here, this assumption can be corroborated for females only. Male individuals display no such coherence difference. The question why coherence seems only sensitive for females in terms of cognitive processes, intelligence and neural efficiency may partly be answered referring to human brains sexual dimorphism.

References

- Beaumont, G.J., Mayers, A.R. and Rugg, M.D. (1978) Asymmetry in EEG alpha coherence and power: effects of task and sex. *Electroencephalogr. Clin. Neurophysiol.*, 45: 393-401.
- Bishop, K.M. and Wahlsten, D. (1997) Sex Differences in the Human Corpus Callosum: Myth or Reality? *Neurosci. Biobehav. Rev.*, 21: 581-601.
- Busk, J. and Galbraith, G.C. (1975) EEG correlates of visual motor practice in man. *Electroencephalogr. Clin. Neurophysiol.*, 38: 415-422.
- Corsi-Cabrera, M., Arce, C., Ramos, J., Guevara, M.A. (1997) Effect of spatial ability and sex on inter- and intrahemispheric correlation of EEG activity. *Electroencephalogr. Clin. Neurophysiol.*, 102: 5-11.
- DeCourten-Myers, G.M. (1999) The Human Cerebral Cortex: Gender Differences in Structure and Function. *J. Neuropathol. Exp. Neurol.*, 58: 217-226.
- Fein, G., Raz, J., Brown, F.F. and Merrin, E.L. (1988) Common reference coherence data are confounded by power and phase effects. *Electroencephalogr. Clin. Neurophysiol.*, 69: 581-584.
- Gasser, T., Jennen-Steinmetz, C. and Verleger, R. (1987) EEG coherence at rest and during a visual task in two groups of children. *Electroencephalogr. Clin. Neurophysiol.*, 67: 151-158.
- Gur, R.C., Mozley, L.H., Mozley, P.D., Resnick, S.M., Karp, J.S., Alavi, A., Arnold, S.E., Gur, R.E. (1995) Sex Differences in Regional Cerebral Glucose Metabolism During a Resting State. *Science*, 267: 528-531.
- Haier, R.J. (1995) Sex Differences and Lateralization in Temporal Lobe Glucose Metabolism During Mathematical Reasoning. *Dev. Neuropsychol.*, 11: 405-414.
- Klimesch, W. (1999) EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Res. Rev.*, 29: 169-195.
- Lynn, R. (1999) Sex differences in intelligence and brain size: a developmental theory, *Intelligence*, 27: 1-12
- Lynn, R., Allik, J. and Must, O. (2000) Sex differences in brain size, stature and intelligence in children and adolescents: some evidence from Estonia. *Pers. Individ. Differ.*, 29: 555-560.
- Mansour C.S., Haier R.J. and Buchsbaum, M.S. (1996) Gender comparison of cerebral glucose metabolic rate in healthy adults during a cognitive task. *Pers. Individ. Differ.*, 20: 183-191.
- Neubauer, A.C., Fink, A. and Schrausser, D.G. (2000) Intelligence and neural efficiency: The influence of task content and sex on brain-IQ relationship. Manuscript submitted for publication.
- Nopoulos P., Flaum, M., O'Leary, D., Andreasen, N.C. (1999) Sexual dimorphism in the human brain: evaluation of tissue volume, tissue composition and surface anatomy using magnetic resonance imaging. *Psychiatry Res.: Neuroimaging Section*, 98: 1-13.
- Nyberg, L., Habib, R. and Herlitz, A. (2000) Brain activation during episodic memory retrieval: Sex differences. *Acta Psychol.*, 105: 181-194.
- Posner, M.I. and Mitchell, R.F. (1967) Chronometric analysis of classification. *Psychol. Rev.*, 74: 392-409.
- Rabinowicz, T., Dean, D.E., McDonald-Comber Petetot, J., DeCourten-Myers, G.M. (1998) Gender Differences in the Human Cerebral Cortex: More Neurons in Males; More Processes in Females. *J. Child Neurol.*, 14: 98-107.
- Reschies, B. and Rappelsberger, P. (1999) Gender dependent EEG-changes during a mental rotation task. *Int. J. Psychophysiol.*, 33: 209-222.
- Skandaries, W., Reik, P. and Kunze, Ch. (1999) Topography of evoked brain activity during mental arithmetic and language tasks: sex differences. *Neuropsychologia*, 37: 421-430.
- Sklar, R.L., Hanley, J. and Simmons, W.W. (1972) An EEG experiment aimed toward identifying dyslexic children. *Nature (Lond.)*, 240, pp. 414-416.
- Thatcher, R.W., McAlaster, R., Lester, M.L., Horst, R.L. and Cantor, D.S. (1983) Hemispheric EEG asymmetries related to cognitive functioning in children. In: E.Perecman (Ed.), *Cognitive Processing in the Right Hemisphere*, Academic Press, New York, pp. 125-146.
- Thatcher, R.W., Krause, P.J. and Hrybyk, M. (1986) Cortico-cortical associations and EEG coherence: A two compartmental model. *Electroencephalogr. Clin. Neurophysiol.*, 64: 123-143
- Weiss, S., Rappelsberger, P. and Petsche, H. (1995) Amplitude and coherence analysis of visual imagery and visual perception. In: M. Eiselt, U. Zweiner and H. Witte (Eds.), *Quantitative and Topological EEG and MEG Analysis*, Universitätsverlag, Jena, pp. 181-186.